Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 154 (2016) 1043 – 1049

Procedia Engineering

www.elsevier.com/locate/procedia

12th International Conference on Hydroinformatics, HIC 2016

Development of a Parallel Computing Watershed Model for Flood Forecasts

Ping Cheng. Liu[a] , Dong Sin. Shih[a]*, Chau-Yi. Chou[b], Cheng-Hsin. Chen[c], Yu-Chi. Wang[c]

[a] *Department of Civil Engineering, National Chung Hsing University, 250 Kuokuang Rd., Taichung 40227,Taiwan.*
[b] *National Center for High-Performance Computing, National Applied Research Laboratories.*
[c] *Taiwan Typhoon and Flood Research Institute, National Applied Research Laboratories.*

Abstract

In this study, using the WASH123D（WAterSHed Systems of 1-D Stream-River Network, 2-D Overland Regime, and 3-D Subsurface Media）numerical model that was developed by the University of Florida professor Ye, its feature is the ability to combine rivers, surface and groundwater with simulation, and it can be used in variety flow. Currently WASH123D has been extended in various research projects, since WASH123D can calculate different kind of cases, the model that is necessary to set a large number of simulation parameters, so it cause a long time to compute. In the research, WASH123D model as the basis for the development of HERO (HypErcomputing wateRshed mOdel) model, HERO model decrease memory usage by reducing the computation of matrix, and add parallelizing calculations to make the subroutine that computation is huge calculate in different core. Then more cores will decrease the computation time in CPU, and then it add the infiltration equation of Green-Ampt Method in the model, reducing the subsequent calculation of the output value. The results, WASH123D mode need to modify the grid for different cases, but HERO mode can accept various cases, and the highest memory usage can be reduced 120bytes , then the method of parallel, OpenMP, effectively reduces the computation time nearly 50%.

Peer-review under responsibility of the organizing committee of HIC 2016

Keywords: WASH123D; OpenMP

Peer-review under responsibility of the organizing committee of HIC 2016
doi:10.1016/j.proeng.2016.07.594

1. Introduction

Taiwan is located at the junction of the Eurasian Plate and the Pacific, where is invaded from typhoon and rainy season in frequency, because the uneven distribution of the rain converge in a short time and the population density is crowded, it is easy to cause serious disasters. On the other hand, the impact of global weather exchange and the intensity and frequency of hydrological events have gradually increased, so establishing atmospheric - hydrological simulation system is necessary. Complete watershed simulation can be divided into three parts of river calculus (one-dimension), surface runoff (two-dimension) and groundwater simulation (three dimension), then there's common package and developed program for user to use ； the model that usually used in Taiwan is the HEC-RAS model which is developed by US Army Corps of Engineers hydrologic Engineering Center, in addition, the US Bureau of Reclamation developed GSTARS model. There're more model developed from different people or company like ； NETSTARS, CCHE1D, EFA1D, FLO-2D, CCHE2D, but those model have their disadvantage in different ways. In the past, distribution hydrological model or physical schema is considered to provide a accurate flow, but the long simulation time has been criticized. As time goes by, there's the GPU (Graphics Processing Unit) computing technology that can let you have hundreds of cores to significantly decrease simulation time. In the research, WASH123D model as the basis for the development of HERO model that can reduce memory usage and decrease simulation time.

2. Mathematical basis of WASH123D

The governing equations of water flow in one-dimensional river/stream/canal can be derived based on the conservation law of water mass and linear momentum(Singh, 1996), and can be written as follows:

The continuity equation:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = S_S + S_R - S_E + S_I + S_1 + S_2 \tag{1}$$

where S_S is the man-induced source [$L^3/T/L$], S_R is the source due to rainfall [$L^3/T/L$], S_E is the sink duo to evapotranspiration [$L^3/T/L$], S_I is the source duo to exfiltration from the subsurface media [$L^3/T/L$], S_1 and S_2 are the source terms contributed from overland flow [$L^3/T/L$].

The momentum equation:

$$\frac{\partial Q}{\partial t} + \frac{\partial VQ}{\partial x} = -gAa\frac{\partial (Z_0 + h)}{\partial x} - \frac{gAh}{c\rho}\frac{\partial \Delta\rho}{\partial x} - \frac{\partial F_X}{\partial x} + (M_S + M_R + M_E + M_I + M_1 + M_2) \tag{2}$$

where h is water depth [L], Z_0 is bottom elevation [L], c is the shape factor of the cross-sectional area, F_X is the momentum flux duo to eddy viscosity [L^4/T^2], M_S is the external momentum-impulse from artificial source/sink [L^3/T^2].

The governing equations for two-dimensional overland flow can be derived based on conservation law of water mass and linear momentum[Wang and Connor, 1975]. The governing equations of dynamic wave model in conservative form can be written as follows:

The continuity equation:

$$\frac{\partial h}{\partial t} + \frac{\partial (uh)}{\partial x} + \frac{\partial (vh)}{\partial y} = S_S + S_R - S_E + S_I \tag{3}$$

where h is water depth[L], S_s is the man-induced source [$L^3/T/L$], S_R is the source due to rainfall [$L^3/T/L$], S_E is the sink duo to evapotranspiration [$L^3/T/L$], S_I is the source from subsurface media duo to exfiltration [$L^3/T/L$].

The x-momentum equation:

$$\frac{\partial(uh)}{\partial t}+\frac{\partial u(uh)}{\partial x}+\frac{\partial v(vh)}{\partial y}=-gh\frac{\partial(Z_0+h)}{\partial x}-\frac{gh^2}{2\rho}\frac{\partial\Delta\rho}{\partial x}-\frac{\partial F_{xx}}{\partial x} -\frac{\partial F_{yx}}{\partial y}+(M_X^S+M_X^R-M_X^E+M_X^I) \tag{4}$$

The y-momentum equation:

$$\frac{\partial(vh)}{\partial t}+\frac{\partial u(vh)}{\partial x}+\frac{\partial v(vh)}{\partial y}=-gh\frac{\partial(Z_0+h)}{\partial y}-gh\frac{gh^2}{2\rho}\frac{\partial\Delta\rho}{\partial y}-\frac{\partial F_{xy}}{\partial x} -\frac{\partial F_{yy}}{\partial y}+\left(M_y^S+M_y^R-M_y^E+M_y^I\right) \tag{5}$$

M_X^S is the x-component of momentum-impulse from artificial sources/sinks [L^3/T^2], F_{xx} and F_{yx} are the water fluxes duo to eddy viscosity along the x direction [L^3/T^2].

3. Mathematical basis of OpenMP

OpenMP is an open industry standard maintained by the OpenMP Architecture Review Board, mainly targeting for homogenous multiprocessor platforms with shared memory. The execution model of OpenMP is a fork-join model of parallel execution as shown in Figure 1-1. In Figure 1-1, an OpenMP program has only one thread initially, called the initial thread. When the initial thread encounters a parallel directive, it forks a team of itself and zero or more additional threads, and becomes the master of the new team. After finishing the parallel region, the team of threads joins together, and, as a result, only the master thread which is the initial thread continues execution. Furthermore, there are implicit synchronizations before and after the parallel regions in order to maintain program correctness. The memory model of OpenMP is shared memory with each thread having its own private memory as shown in Figure 1-2. Data can be shared data are accessible by all threads; in contrast, private data can only be accessed by thread owning it.

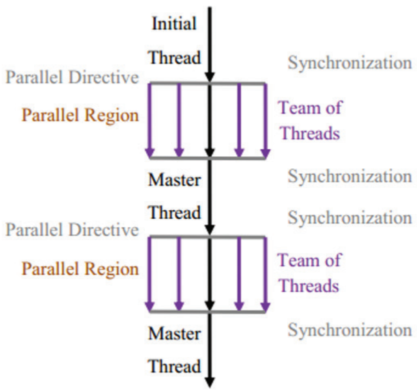

Fig. 1-1. The Execution Model of OpenMP

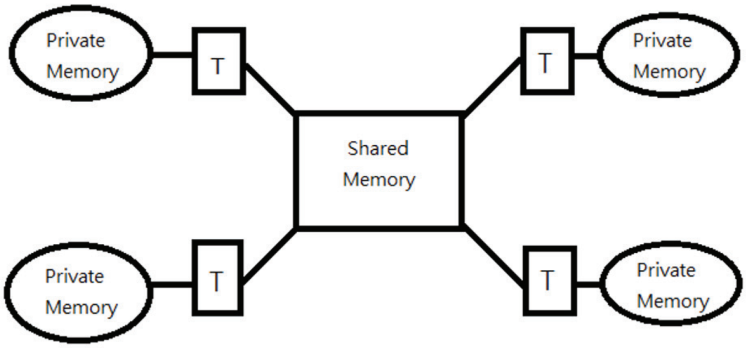

Fig. 1-2 The Memory Model of OpenMP

Fig. 1-1. and Fig. 1-2. references to the article of Tsai, Tsung-Chen, 2010,

4. Memory usage

There are two aspect to discuss the memory usage for one-dimensional and two-dimensional in different model. HERO model can calculate different cases that the model didn't need to reset the initial matrix, otherwise, WASH123D model need to do it. The size of matrix decide the memory usage you use, but the memory usage include the real memory and the virtual memory. If you set a matrix that is bigger than it need, it will provide extra virtual memory for the program. More memory usage cause more computation time. If the program can be applicable to the matrix in different cases, the memory can be reduced.

The one-dimensional case is Pingtung river that include four rivers. There are 183 nodes and 178 elements in Pingtung river and the initial discharge set in the elements on the upstream in Table 1. There are 7 material in different elements as shown in Table 2. In Table 2, the manning coefficient are 0.042, 0.040, 0.036, 0.034, 0.032, 0.030, 0.028. Simulation shows that HERO model can reduce memory usage more than WASH123D, and the simulation value are the same for both HERO and WASH123D as shown in Figure 1-3. The total simulation time is 259200 seconds and the time step is 10 seconds. In Figure 1-3, the red squares are the value of WASH123D model, the black circles are the value of HERO model, x-axis is nodes, and y-axis is water depth.

Table 1. Simulation parameters

Nodes	Elements	Initial discharge (cms)		
183	178	8.9	0.2	8.1

Table 2. Manning coefficient

Elements	Manning coefficient
1~8	0.042
9~72	0.04
73~82	0.036
83~108	0.04
109~128	0.034
129~136	0.032
137~157	0.03
158~178	0.028

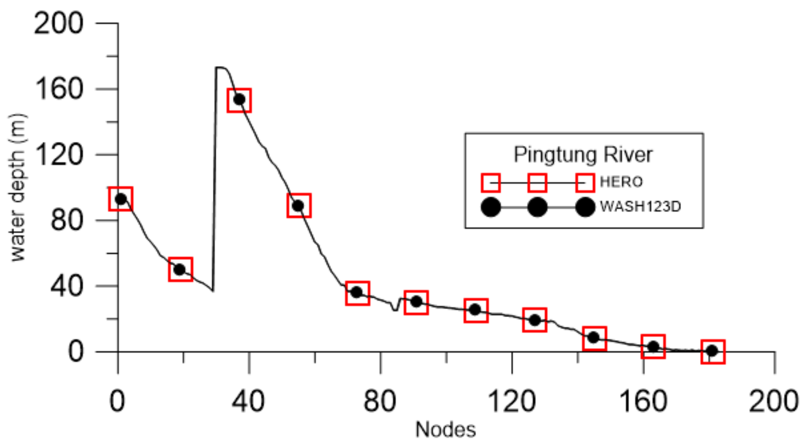

Fig. 1-3. the result of HERO model and WASH123D model

The two-dimensional case is Lan Yang river that area has 1313 square-kilometer. There are 32906 nodes and 65357 elements in Lan Yang river. In the study, the simulation parameters reference to Lin, To (2015) who set the manning coefficient of Lan Yang river by the land usage classification as shown in Table 3. In Table 3, the manning coefficient of Lan Yang river are 0.20, 0.30, 0.15, 0.10, 0.15. Lan Yang river display as show in Figure1-4. In Figure1-4, the land usage of Lan Yang river. Simulation shows that HERO model can reduce memory usage more than WASH123D, and the result are the same for both HERO and WASH123D as shown in Figure 1-5. The total simulation time is 259200 seconds and the time step is 10 seconds. In Figure 1-5, Lan Yang river display from blue to red that means the flood potential is getting hard and the range of flood potential value set from 0.0 to 1.0.

Table 3 Simulation parameters of Lan Yang river

The land usage	Agricultural	Forest	Transportation	Channal	Architecture	Other
Manning coefficient	0.20	0.30	0.10	0.5	0.15	0.20

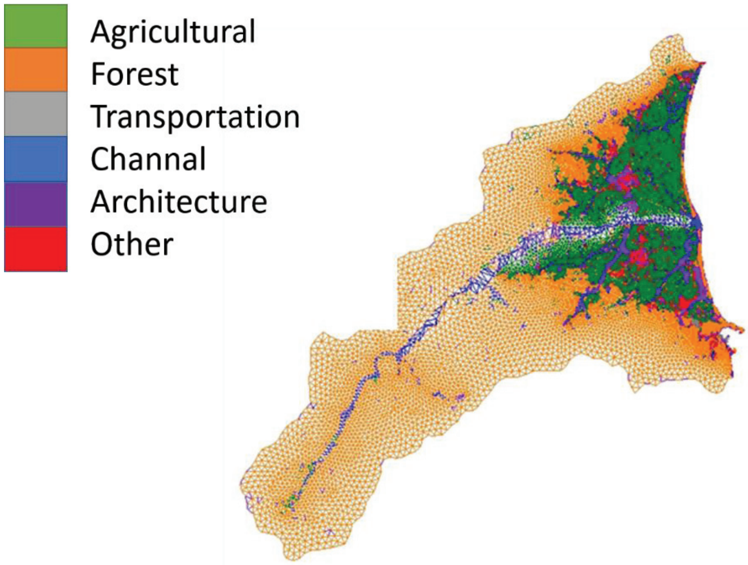

Fig. 1-4. Lan Yang river display by land usage

(a) (b)

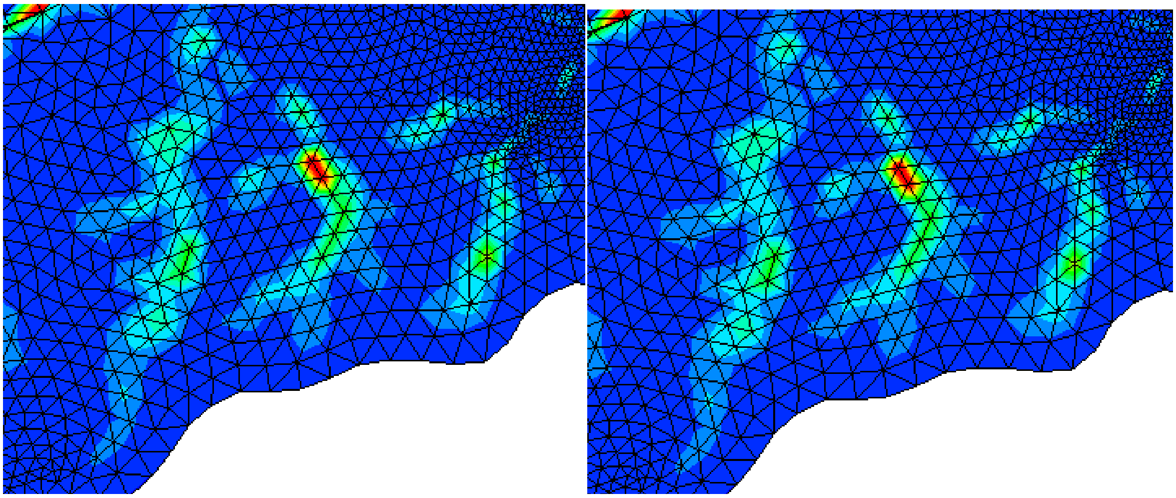

Figure 1-5 the result for the flood potential of Lan Yang river, HERO model is (a) and WASH123D model is (b) . The range of flood potential vaule set from 0.0 ~ 1.0.

Parallel computation

In the study, we add the parallel algorithms with OpenMP in two-dimensional. The subroutine which cause the most simulation time use multi-core to execute it then we try to test how many core will spend least simulation time. The case is Lan Yang river for two-dimensional and it tests in different core as shown in Table 4. In Table 4, the result is simulated in 259200 second and the time step is 10 second. There are the simulation time of the subroutine corresponded with different core as shown in Figure 1-6.

Table 4 Simulation time

core	Total simulation	Subroutine simulation time (s)
1	1 hour 20 min 15 sec	2868.819 sec
2	49 min 36 sec	1298.389 sec
4	47 min 01 sec	935.603 sec
8	46 min 44 sec	688.850 sec
12	50 min 21 sec	658.113 sec

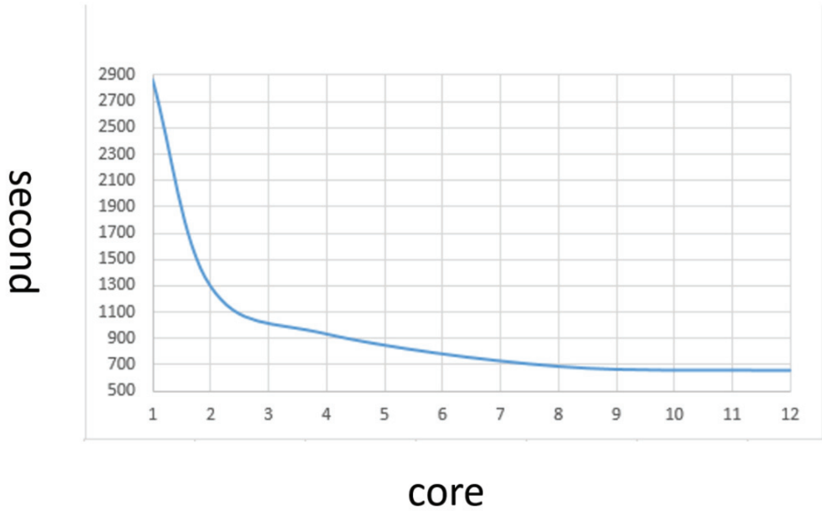

Fig. 1-6. the effect of multi-core from Table 4

5. Conclusion.

The result of memory usage show HERO model compute real memory only, otherwise, WASH123D model compute both real memory and virtual memory that cause the program improve more memory usage. Parallel algorithms with OpenMP has an well effect in two-dimensional and the result show that Lan Yang river with 8 core is the best. HERO model reduce simulation time more than WASH12D model about 20 minutes. After, we want to discuss how many core is the effective for different elements and make sure that the core relate to the elements is positive or not.

References

[1] Lin, To , Integrating Numerical Simulation and Fuzzy Theory to Optimize the Flood Forecasting, Taiwan, 2015, pp.90.

[2] Tsai, Tsung-Chen, OMP2OL Translator for Automatic Translation of OpenMP Programs into OpenCL Programs, Taiwan ,2010, pp.38.

[3] Yeh, Gour-Tsyh, Huang, Guobiao, Zhang, Fan, Cheng, Hwai-Ping, and Lin, Hsin-Chi., WASH123D：A Numerical Model of Flow, Thermal Transport, and Salinity, Sediment, and Water Quality Transport in WAterSHed System of 1-D Stream-River Network, 2-D Overland Regime, and 3-D Subsurface Media., Taiwan, 2005. pp.460.